Methods to Find the Cost-Effectiveness of Funding Air Quality Projects

For Evaluating
Motor Vehicle Registration Fee Projects
and
Congestion Mitigation and
Air Quality Improvement (CMAQ) Projects

1999 EDITION

California Environmental Protection Agency

Air Resources Board

Caltrans

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The methods handbook was prepared by the California Air Resources Board (ARB) in cooperation with the California Department of Transportation (Caltrans) and the California Air Pollution Control Officers Association (CAPCOA). The principal author is Pam Burmich, Air Pollution Specialist.

FOR COPIES *of this handbook, see the ARB or Caltrans websites at* ***www.arb.ca.gov*** *or* ***www.dot.ca.gov/hq/TransPrg/****, or call the ARB's Transportation Strategies Group at (916) 323-0439. The handbook is also available as a Microsoft Access file that allows the user to enter the appropriate inputs and calculates emission reductions and cost-effectiveness automatically.*

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Introduction

Millions of dollars are provided each year to regional and local jurisdictions to help fund projects that reduce emissions from motor vehicles and assist the implementation of transportation measures in regional clean air plans. Two major sources of this funding are the California Motor Vehicle Registration Fee (MV Fees) Program and the federal Congestion Mitigation and Air Quality Improvement (CMAQ) Program.

To ensure that public health benefits are maximized, it is important that projects funded be the most cost-effective at reducing emissions. To achieve this goal, cost-effectiveness evaluations should be used to prioritize projects before final funding decisions are made.

The cost-effectiveness of an air quality project is based on the amount of pollution it eliminates for each dollar spent. This document is a "methods handbook" to help estimate the cost-effectiveness of some of the most widely implemented transportation-related air quality projects:

Cleaner off-road vehicles	Signal coordination
Cleaner on-road vehicles	Bicycle facilities
New bus service	Telecommuting programs
Vanpools and shuttles	Ridesharing and pedestrian facilities

For each project type, the methods handbook includes:

- A list of the information needed to evaluate cost-effectiveness.
- "Defaults" that may be used when data is not available.
- Formulas to calculate vehicle emission reductions for three major pollutants:

  Reactive organic gases (ROG)
  Nitrogen oxides (NOx)
  Particulate Matter (PM10)

  Emission factor tables are included for various vehicle and project types.

- Formula to calculate cost-effectiveness
- Sample evaluation to aid in using the method

Cost-Effectiveness

Cost-effectiveness for MV Fees and CMAQ projects should be expressed as dollars spent per pound of pollutant reduced (ROG + NOx + PM10). Cost-effectiveness is typically based on total project costs, including capital investments and operating costs. However, for the purposes of this document, cost-effectiveness is based on clean air funding dollars. Project funding generally covers only the incremental additional costs of a cleaner engine or vehicle.

The funding dollars are amortized over the expected project life using a discount rate. The amortization formula yields a capital recovery factor, which, when multiplied by the funding, gives the annual funding for the project over its expected lifetime. The discount rate reflects the opportunity cost of public funds for the clean air programs. This is the level of earning that could be reasonably expected by investing public funds in various financial instruments, such as U.S. Treasury securities. Cost-effectiveness is determined by dividing annualized funds by annual emission reductions (ROG + NOx + PM10).

The following table gives capital recovery factors that may be used to annualize funding dollars according to project life. The capital recovery factors calculated to two decimal places are the same for discount rates 4.75% and 5%.

Project Life	**Capital Recovery Factor for discount rates 4.75% or 5%**
1 year	1.05
3 years	0.37
5 years	0.23
7 years	0.17
10 years	0.13
12 years	0.11
15 years	0.10
20 years	0.08

Defaults

The methods in this handbook call for monitored data and information inputs that may not be readily available. Defaults are provided for each method based on local and national travel surveys, surveys conducted by local air districts, research projects funded by the Air Resources Board (ARB) and air districts, and ARB guidance documents. Local data should be used in place of defaults when data is available. Emission factors are based on certification testing and ARB's statewide mobile source inventory.

Federal CMAQ Reporting Requirements

Carbon monoxide. Federal Highway Administration (FHWA) requests that CO emission reductions be reported for CMAQ projects. California's MV Fee Program does not request CO information. CO is a localized pollutant and not a regional pollution problem. Most projects using CMAQ and MV Fee dollars are funded primarily to reduce regional ozone and PM10 and have little impact on localized CO hot spots.

Signal coordination projects, however, may be targeted at specific CO hot spots in CO nonattainment areas. CO emission factors are included in the 1999 Edition in order to report to FHWA on these types of CMAQ projects. Reporting CO emission reductions should be limited to targeted projects located in CO nonattainment areas (Los Angeles and Imperial counties) or projects in CO maintenance areas.

In addition, CO emissions are several orders of magnitude larger than ozone precursors. CO overwhelms cost-effectiveness ratios unless CO emission reductions are scaled back significantly, typically by a factor of seven. This adjustment should be made when using cost-effectiveness ratios as a basis for funding decisions. Another option is to consider CO projects separately from ozone precursor projects.

Kilograms. FHWA requests that emission reductions from CMAQ projects be reported in kilograms per day. The methods handbook therefore includes formulas to convert pounds per year of emission reductions to kilograms per day.

Infrastructure Projects

Supporting infrastructure may be necessary for some kinds of emission reducing projects to be successful. Examples of infrastructure projects are alternative-fueled vehicle refueling stations, electric vehicle recharging facilities, public education programs, multi-modal transit infrastructure projects, and automated transit schedule information. Because infrastructure projects are difficult to evaluate for cost-effectiveness, they are not included in this handbook. However, they should be evaluated with respect to their consistency with clean air plans. Funding priorities can be structured to include supporting projects.

Mobile Source Emission Reduction Credits

The methods handbook should not be used to determine mobile source credits which can be sold or traded. For procedures on how to generate these credits, please refer to the Air Resources Board document, Mobile Source Emission Reduction Credits Guidelines.

Air Resources Board regulations require new motor vehicles (including transit buses) to meet progressively more stringent emission standards. Emission reductions associated with the natural replacement of older vehicles with newer, cleaner models are included in motor vehicle emission inventories in clean air plans, and thus are not new emission reductions. Since Mobile Source Credits may be sold or traded, they must go beyond the emission reductions already accounted for in clean air plans.

On-Road Cleaner Vehicle Purchases and Repowering

Project definition: The purchase of a motor vehicle that is certified to be less polluting than a typical new vehicle (cleaner purchase) or an engine replacement that transforms a vehicle into a less polluting one (cleaner repower). For heavy-duty on-road vehicles, these projects are usually the purchase of a cleaner, alternative-fueled engine or vehicle instead of a new conventional diesel-fueled engine or vehicle. Since natural replacement of older vehicles or engines with newer, cleaner ones (fleet turnover) is accounted for in clean air plans, in order to claim emission reductions from the project, the vehicles purchased must emit less pollution than conventional new vehicles meeting current emission standards.

How emissions are reduced: Emission reductions are the difference between the emissions associated with a new, more polluting vehicle minus the emissions associated with a new, less polluting vehicle.

Need to know:
Funding dollars
Annual vehicle miles traveled (VMT)
Engine certification rates or cleaner vehicle classification

Inputs	Default	Units	Comments
Funding Dollars (**Funding**)		dollars	
Effectiveness Period (**Life**)	12	years	Suggested defaults are: Cleaner heavy-duty transit or urban bus - 12 Electric bus - 18, School bus - 20, Heavy-duty trucks - 10, Medium-duty vehicles - 10, Light-duty vehicles - 8 Light-duty electric vehicles - 10
Annual Vehicle Miles Traveled (**VMT**)		annual miles	Transit bus - 40,000 mi/yr School bus - 15,000 mi/yr Heavy-duty truck - 29,000 mi/yr (based on engine life of 290,000 mi.)

Emission Factor Inputs (Example is for Transit Buses)

	Default	Units	Default	Units
	Before Emission Factor		**After Emission Factor**	
ROG Factor		g/mi		g/mi
NOx Factor	17.2	g/mi	8.6	g/mi
PM10 Factor		g/mi		g/mi

To locate emission factors, refer to emission factor tables at the end of the document. The defaults above are for heavy-duty transit buses. Benefits for heavy-duty vehicles are usually based on NOx emissions only. The "Before" Emission Factor (17.2 g/mi) represents a typical new diesel bus engine. The "After" Emission Factor (8.6 g/mi) represents a compressed natural gas (CNG) bus engine certified to 2.0 g/bhp-hr. Electric buses use 0 as default value.

For more information on heavy-duty emission factors, see Table 5, On-Road Nitrogen Oxides (NOx) Emission Factors for Heavy-Duty Cleaner Vehicle Projects (1998-1999). For medium-duty vehicle and light-duty emission factors, see Table 2 and Table 7. Select the factors that best represent your project. Another source for emission factors is the engine's original manufacturer.

Formulas	**Units**
Annual Emission Reductions (ROG, NOx, and PM10) = (VMT)*[(Before Emission Factor) - (After Emission Factor)]/454	lbs/year

Capital Recovery Factor (CRF) = $\dfrac{(1 + i)^n\,(i)}{(1 + i)^n - 1}$

where: i = discount rate (Assume 5 percent)
n = project life

Cost-Effectiveness of Funding Dollars = (CRF * Funding) / (ROG + NOx + PM10)	dollars/lb

Note: The Federal Highway Administration requests that emission reductions from CMAQ projects be reported as kilograms/day. The conversion is

(lbs per year) / [(2.2) (365)] = kilograms/day*

On-Road Cleaner Vehicle Purchases and Repowering (Optional Method)

Emissions can also be calculated using emission factors in units of g/bhp-hr multiplied by annual fuel consumption and an energy consumption factor. The default for the energy consumption factor is 18.5 hp-hr/gal. In the formula above, substitute annual gallons of fuel in place of **VMT**. Substitute emission rates in units of g/bhp-hr multiplied by 18.5 in place of the **Before Emisson Factor** and the **After Emission Factor**.

Purchase CNG Transit Buses

A transit provider is purchasing 19 40-foot CNG transit buses to replace existing diesel buses. The vehicles will be equipped with the Cummins 2.0 g/bhp-hr NOx dedicated CNG engine.

Inputs to calculate cost-effectiveness:

Funding Dollars (Funding) = $760,000 (The CNG buses cost $40,000 per bus more than the diesel buses.)

Effectiveness Period (Life): 12 years

Annual Vehicle Miles Traveled (VMT): 988,000 miles
(19 buses travel 52,000 miles annually per bus).

Emissions Factors (From Table 5):

	"Before" Emission Factor	"After" Emission Factor
ROG Factor	not applicable	not applicable
NOx Factor	17.2	8.6
PM10 Factor	not applicable	not applicable

Calculations:

Annual Emission Reductions (ROG, NOx, and PM10) =
(VMT) * [(Before Emission Factor) - (After Emission Factor)]/454

ROG: 0 lbs. per year reduced
NOx: 988,000 * [(17.2) - (8.6)]/454 = **18,715 lbs. per year reduced**
PM10: 0 lbs. per year reduced

Capital Recovery Factor (CRF) $= \frac{(1+i)^n(i)}{(1+i)^n - 1}$ *where:* *n = project life (12 years)*
(From Table 8) *i = discount rate (5%)*

$$CRF = \frac{(1+.05)^{12}(.05)}{(1+.05)^{12} - 1} = 0.11$$

Cost-Effectiveness of Funding Dollars = (CRF * Funding) / (ROG + NOx + PM10)
=(0.11 * 760,000) / (0 + **18,715** + 0)
= **$4 per lb.**

FOR CMAQ PROJECTS ONLY:

Once emissions reductions have been calculated, add them together (0 + 19,586 + 0 = 19,586) and
convert emissions reductions per year to kg/day:

$$\frac{\text{lbs. per year}}{2.2 \text{ lbs./kg} * 365 \text{ days/year}} = \frac{\mathbf{18,715}}{2.2 * 365} = \mathbf{23 \text{ kg/day}}$$

Off-Road Cleaner Vehicle Purchases and Repowering

Project definition: Replacing uncontrolled diesel engines in off-road equipment, such as agricultural or construction equipment, with lower-emitting, controlled diesel engines or alternative fueled engines. Repowering vehicles with cleaner new engines is done instead of rebuilding the old engine. Diesel engines, rather than alternative fueled engines, are typically used to meet the needs of these applications.

How emissions are reduced: Emission reductions are the difference between the emissions associated with an older rebuilt, more polluting engine minus the emissions associated with the less polluting new engine. Emission reductions are primarily NOx reductions.

Need to know:
Funding dollars
Annual vehicle operating hours
Horsepower
Engine load factor

Inputs	Default	Units	Comments
Funding Dollars (**Funding**)		dollars	
Effectiveness Period (**Life**)	10	years	
Annual Vehicle Operating Hours (**OperHrs**)		annual hours	Operating hours range: Agricultural Equipment 110 - 814 Construction Equipment 130-1836
Horsepower (**HP**)		bhp	
Load			Load range: Agricultural Equipment 0.38 - 0.7 Construction Equipment 0.43-0.78

Emission Factor Inputs
Default **Units** **Default**
Units

	Before Emission Factor		After Emission Factor	
ROG Factor				
NOx Factor	13.0	g/bhp-hr	6.9	g/bhp-hr
PM10 Factor				

To locate emission factors, refer to emission factor tables at the end of the document. Benefits for off-road vehicle engines are usually based on NOx emissions only. The "Before" Emission Factor (13.0 g/bhp-hr) represents a typical old diesel engine. The "After" Emission Factor (6.9 g/bhp-hr) represents a new diesel engine. For more information on emission factors, see Table 6, Off-Road Nitrogen Oxides (NOx) Emission Factors for Cleaner Vehicle Projects. (ARB will consider an updated off-road emissions model in late 1999.)

Formulas **Units**

Annual Emission Reductions (ROG, NOx, and PM10) = lbs/year

(OperHrs)*(HP)*(Load)*[(Before Emission Factor) - (After Emission Factor)]/454

Capital Recovery Factor (CRF) = $\frac{(1 + i)^n (i)}{(1 + i)^n - 1}$

where: i = discount rate (Assume 5 percent)
n = project life

Cost-Effectiveness of
Funding Dollars = (CRF * Funding) / (ROG + NOx + PM10) dollars/lb

Note: The Federal Highway Administration requests that emission reductions from CMAQ projects be reported as kilograms/day. The conversion is
(lbs per year) / [(2.2) (365)] = kilograms/day*

Off-Road Cleaner Vehicle Purchases and Repowering (Optional Method)

Annual operating hours (**OperHrs**), horsepower (**HP**), and Load (**L**) can be replaced in the formula with annual fuel consumption in gallons per year multiplied by an energy consumption factor expressed as hp-hr/gal. The default for the energy consumption factor is 18.5 hp-hr/gal. In the formula above, substitute annual gallons of fuel in place of **OperHrs**. Substitute 18.5 in place of **HP*Load**.

Agricultural Sprayer Engine Repower

A company proposes to re-power two agricultural sprayers with new diesel engines.
The new diesel engines will emit 6.9 g/bhp-hr of NOx compared to the old engines rebuilt to emit 13 g/bhp-hr.

Inputs to calculate cost-effectiveness:

Funding Dollars (Funding) = $8,000
Effectiveness Period (Life): 10 years
Annual Vehicle Operating Hours (Oper Hrs): 740 hours per year
    where each engine operates for 370 hrs/ year.
Horse Power (HP): 100 hp
Load factor: 0.5

Emissions Factors: (From Table 6)

	"Before" Emission Factor	"After" Emission Factor
ROG Factor	not applicable	not applicable
NOx Factor	13 grams/ bhp-hr	6.9 grams/ bhp-hr
PM10 Factor	not applicable	not applicable

Calculations

Annual Emission Reductions (ROG, NOx, and PM10) =
    (Oper Hrs) * (HP) * (Load) * [(Before Emission Factor) - (After Emission Factor)] / 454

ROG: 0
NOx: (740)*(100)*(0.5)*[(13) - (6.9)]/454 = **497 lbs. per year reduced**
PM10: 0

Capital Recovery Factor (CRF) $= \frac{(1+i)^n(i)}{(1+i)^n - 1}$ *where: i = discount rate (assume 5 percent)*
(From Table 8) *n = project life (10 years)*

$$CRF = \frac{(1+.05)^{10}(.05)}{(1+.05)^{10} - 1} = 0.13$$

Cost-Effectiveness of Funding Dollars = (CRF * Funding)/(ROG + NOx + PM10)
=(0.13 * 8,000) / (497)
= $2 per lb.

FOR CMAQ PROJECTS ONLY:

Once emissions reductions have been calculated, add them together (0+ 497 +0 = 497) and convert emissions reductions to kg/day: $\frac{\textit{lbs. per year}}{\textit{2.2 lbs./kg * 365 days/year}} = \frac{497}{2.2 * 365} =$ ***1 kg/day***

Operation of New Bus Service

Project definition: New, extended, and increased-frequency routes with cleaner, alternative fueled vehicles provide new hours of bus service per year and serve additional people. These are fixed-route services implemented by transit agencies or school districts. Cleaner, alternative-fueled vehicles should be used in bus service expansions in order to achieve emission reductions from the project. For example, a typical urban transit bus with a new diesel engine (4.0 g/bhp-hr NOx) needs to operate at capacity (40 bus riders) in order to offset the NOx emissions associated with the bus itself. Cleaner, alternative-fueled buses (i.e., 2.0 g/bhp-hr NOx) will offset bus emissions with half as many bus riders.

How emissions are reduced: Emission reductions result from the decrease in emissions associated with auto trips replaced by the new bus service after adjusting for the added bus emissions and auto access.

Need to know:
Funding dollars
Number of operating days per year
Average daily ridership of new service (usually less than 100% occupancy)
Average length of auto trips replaced
Percent of riders who drive to the bus service
Annual VMT for the new bus service

Inputs	Default	Units	Comments
For the Bus Service			
Funding Dollars (**Funding**)		dollars	
Effectiveness Period (**Life**)	1	years	Years project is funded.
Days (**D**)	260	days (of operation)/year	Suggested defaults are weekday services - 260 days, daily services - 365 days, school bus services - 180 to 200 days
Ridership (**R**)		total trips (bus riders)/day	
Annual Bus VMT (**Bus VMT**)		annual miles traveled	
For Auto Travel Reduced			Auto travel defaults are based on local information.
Adjustment (**A**) on Auto Trips for transit dependent	0.5		This factor equals the portion of transit riders who are NOT transit dependent. Use 0.83 as the adjustment for commuter bus service.

Inputs	Default	Units	Comments
Auto Trip Length (**L**)	9	miles one direction/trip	Length of average auto trips reduced. Other suggested defaults are work trip bus services - 16 mi., school bus - 3 mi.
For Auto Travel Added to Access Bus Service			
Adjustment (**AA**) on Auto Trips for Auto Access to and from transit service	0.5		This factor equals the portion of riders who drive to the transit service. Use 0.8 as the adjustment for long-distance commuter service.
Trip Length (**LL**) for Auto Access to and from transit	2	miles one direction/trip	Use 5 miles for long-distance bus service.

Emission Factor Inputs for Auto Travel

	Default	Units	Default	Units
	Auto Trip End Factor		**Auto VMT Factor**	
ROG Factor	4.98	grams/trip	0.55	grams/mile
NOx Factor	2.05	"	1.02	"
PM10 Factor	0	"	0.45	"

To locate emission factors, refer to emission factor tables at the end of the document. Defaults are for 1 to 5 years effectiveness period. See Table 3 to select emission factors for different effectiveness periods.

Emission Factor Inputs for Clean, Alternative-Fueled Bus Travel

	Default	Units
	Bus VMT Factor	
ROG Factor	3.1	grams/mile
NOx Factor	8.6	"
PM10 Factor	0.6	"

Defaults are for a compressed natural gas transit bus engine (2.0 g/bhp-hr NOx) model year 1998. (See Table 5.) Table 1 also provides emission factors for older diesel buses for purposes of comparison. For newer diesel buses or newer cleaner, alternative fueled buses, see Table 5.

Formulas	**Units**
Annual Auto Trips Reduced = [(D)*(R)*(A)]*[1 - (AA)]	trips/year
Annual Auto VMT Reduced = [(D)*(R)*(A)]*[(L) - (AA)*(LL)]	miles/year

Annual Emission Reductions (ROG, NOx, and PM10) = lbs/year

[(Annual Auto Trips Reduced)*(Auto Trip End Factor)
+ (Annual Auto VMT Reduced)*(Auto VMT Factor)
- (Bus VMT)*(Bus VMT factor)]/454

Capital Recovery Factor (CRF) = $\dfrac{(1 + i)^n (i)}{(1 + i)^n - 1}$

where: i = discount rate (Assume 5 percent)
n = project life

Cost-Effectiveness of
Funding Dollars = (CRF * Funding) / (ROG + NOx + PM10) dollars/lb

Note: The Federal Highway Administration requests that emission reductions from CMAQ projects be reported as kilograms/day. The conversion is

(lbs per year) / [(2.2) (365)] = kilograms/day*

Commuter Express CNG Bus Service

An 80-mile subscription commute bus service operates using five, 40-passenger compressed natural gas (CNG) buses.

Inputs to calculate cost-effectiveness:

Funding Dollars (Funding): $96,600
Effectiveness Period (Life): 1 year
Days of use/year (D): 252
Daily Ridership (R): 40 passengers * 5 buses *2 ways = 200 * 2 = 400 bus riders or trips/day
Annual Bus VMT (Bus VMT): 201,600 (5 buses * 80 miles one-way * 2 ways * 252 days = 201,600 VMT)
Adjustment (A) on Auto Trips for transit dependent: 0.83
Auto Trip Length (L): 80 miles in one direction
Adjustment (AA) on Auto Trips for Auto Access to and from transit: 0.80
Trip Length (LL) for Auto Access to and from transit: 5 miles one-way.

Emissions Factors for Auto Travel (From Table 3):

	Auto Trip End Factor	Auto VMT Factor
ROG Factor	4.98 grams per trip	0.55 grams per mile
NOx Factor	2.05	1.02
PM10 Factor	0	0.45

Emissions Factors for Clean, Alternative-Fueled Long Distance Commuter Bus Travel (From Table 1):

	Bus VMT Factor
ROG Factor	1.1 grams per mile
NOx Factor	6.3
PM10 Factor	0.5

Calculations:

Annual Auto Trips Reduced = [(D)*(R)*(A)]*[1-(AA)]
=[252 * 400 * 0.83]*[1-0.80]
= 16,733 annual auto trips

Annual Auto VMT Reduced = [(D) *(R)*(A)] * [(L) - (AA) * (LL)]
=[252 * 400 * 0.83] * [80-0.80*5]
=[83,664] * [80-4]
= 6,358,464 annual miles

Annual Emission Reductions = (lbs. per year)

[(Annual Auto Trips Reduced) * (Auto Trip End Factor) +
(Annual Auto VMT Reduced) * (Auto VMT Factor) -(Bus VMT)*(Bus VMT Factor)]/454

ROG: [(16,733) * (4.98) + (6,358,464) * (0.55) - (201,600) * (1.1)]/454 = **7398 lbs. per year**
NOx: [(16,733* 2.05 + 6,358,464 * 1.02) - (201,600) * (6.3)]/454 = **11,564 lbs. per year**
PM10: [(16,733 * 0 + 6,358,464 * 0.45) - (201,600) * (0.5)]/454 = **6080 lbs. per year**

Capital Recovery Factor (CRF) = $\frac{(1 + i)^n(i)}{(1 + i)^n - 1} = \frac{0.0525}{0.05} = 1.05$ *n = project life (1 year)*
(From Table 8) *i= discount rate (5%)*

Cost-Effectiveness of Funding Dollars = (CRF * Funding) / (ROG + NOx + PM10)
= (1.05 * 96,600) / (7398 + 11564 + 6080) = **$4 per lb.**

FOR CMAQ PROJECTS ONLY:

Once emissions reductions have been calculated, add them together (7398 + 11564 + 6080 = 25,042) and convert emissions reductions to kg/day:

$$\frac{\text{lbs. reduced per year}}{2.2 \text{ lbs./kg} * 365 \text{ days/year}} = \frac{25{,}042}{2.2 * 365} = \textbf{31 kg/day}$$

Vanpools and Shuttles

Project definition: Projects are commuter vanpools; tourist or shopping shuttles; or rail feeders to work sites, homes, or schools. Services are operated by transit agencies, local governments, transportation management associations (TMAs), private businesses, etc. In most cases, the shuttle service must reduce long-distance auto trips or be a cleaner vehicle in order to reduce emissions cost effectively.

How emissions are reduced: Emission reductions result from the decrease in emissions associated with auto trips replaced by the vanpool or shuttle service after adjusting for the increase in emissions associated with the shuttle vehicle itself and auto access trips.

Need to know:
Funding dollars
Number of operating days per year
Average daily ridership of new service (usually less than 100% occupancy)
Average length of auto trips replaced
Percent of riders who drive to the vanpool or shuttle service
Daily VMT for the new shuttle service

Inputs	Default	Units	Comments
For the Vanpool/Shuttle			
Funding Dollars (**Funding**)		dollars	
Effectiveness Period (**Life**)	1	years	Years project is funded.
Days (**D**)	250	days (of operation)/year	Suggested defaults are weekday vanpools - 250 days, weekday shuttles - 260, daily services - 365 days, school services - 180 to 200 days
Ridership (**R**)		total trips (riders)/day	One-way trips by riders (or number of boardings)
Annual Van/Shuttle VMT (**Van VMT**)		annual miles	
For Auto Travel Reduced			
Adjustment (**A**) on Auto Trips	0.3		This factor equals the portion of riders who did NOT previously use transit, vanpools, or carpools. The default (0.3) is the adjustment for new rail feeders. For long-distance, commuter vanpool service, use 0.83 as the adjustment factor A.
Auto Trip Length (**L**)	35	miles one direction/trip	Suggested defaults are vanpools - 35 mi., shuttle trips - 16 mi.

Inputs	Default	Units	Comments
For Auto Travel Added to Access Vanpool/Shuttle			
Adjustment (**AA**) for Auto Access to and from vanpool/shuttle	0.5		Enter the percentage of riders who drive to the vanpool/shuttle service. The default is for rail feeders. For long-distance vanpools, enter 0.75
Trip Length (**LL**) for Auto Access to and from vanpool/shuttle	2	miles one direction/trip	The default (2 mi) is for rail feeders. For long-distance vanpools, enter 5 miles.

Emission Factor Inputs for Auto Travel

	Default	Units	Default	Units
	Auto Trip End Factor		**Auto VMT Factor**	
ROG Factor	4.98	grams/trip	.55	grams/mile
NOx Factor	2.05	"	1.02	"
PM10 Factor	0	"	.45	"

To locate emission factors, refer to emission factor tables at the end of the document. Defaults are for 1 to 5 years effectiveness period. See Table 3 to select emission factors for different effectiveness periods.

Emission Factor Inputs for Van/Shuttle Travel

	Example (1997)	Units
	Van VMT Factor	
ROG Factor	0.58	grams/mile
NOx Factor	1.60	"
PM10 Factor	0.56	"

Defaults are for medium-duty vehicle (weight 8,501 - 10,000 lbs), model year 1997. See Table 2 to select emission factors for vehicles cleaner than standards.

Formulas **Units**

Annual Auto Trip Reduced = [(D) * (R) * (A)]*[1-(AA)] trips/year

Annual Auto VMT Reduced = [(D) * (R) * (A)]* [(L) - (AA)*(LL)] miles/year

Annual Emission Reductions (ROG, NOx, and PM10) = lbs/year

[(Annual Auto Trips Reduced)*(Auto Trip End Factor)
+ (Annual Auto VMT Reduced)*(Auto VMT Factor)
- (Van VMT)*(Van VMT Factor)]/454

$$\text{Capital Recovery Factor (CRF)} = \frac{(1+i)^n\,(i)}{(1+i)^n - 1}$$

where: i = discount rate (Assume 5 percent)
n = project life

Cost-Effectiveness of
Funding Dollars = (CRF * Funding) / (ROG + NOx + PM10) dollars/lb

Note: The Federal Highway Administration requests that emission reductions from CMAQ projects be reported as kilograms/day. The conversion is

(lbs per year) / [(2.2) (365)] = kilograms/day*

Suburban Vanpool/Carpool Park-and-Ride Lots (Method Variation)

Provision of park-and-ride lots may encourage the formation of vanpools and carpools. The emission reduction benefits from park-and-ride lots can be calculated using the above Vanpools and Shuttles methodology plus the following calculation to estimate Ridership (**R**).

Ridership (**R**) = (**Parking**)*(**Lot Utilization**)*(2 commute trips/day)

Where:
Parking is the number of parking spaces for a new parking lot or the number of added spaces to an existing lot. **Lot Utilization** is the estimated lot utilization rate from monitored data OR use 0.75 as a default. Also, when using the vanpool/shuttle methodology for park-and-ride lots, the default for Adjustment (**AA**) for Auto Access to and from vanpool/shuttle should be 0.9 instead of 0.5.

Long-Distance Commuter Vanpools

This project subsidizes 97 long-distance commute vanpools. On average, each vanpool carries 11 people to work. The average distance to work is 48 miles. The vans used are 1995-model year.

Inputs to calculate cost-effectiveness:

Funding Dollars (Funding): $170,352
Effectiveness Period (Life): 1 year
Days of use/year (D): 250
Daily Ridership (R): 11 passengers * 97 vans * 2 ways = 2,134 riders or trips/day
Annual Van VMT (Van VMT): 2,328,000 (If you don't know the van mileage, you can estimate it:
97 vans * 2 ways * 250 days * 48 miles one-way = 2,328,000)
Adjustment (A) on Auto Trips: 0.83
Auto Trip Length (L): 48 miles in one direction
Adjustment (AA) on Auto Trips for Auto Access to and from vanpool: 0.75
Trip Length (LL) for Auto Access to and from vanpool: 5 miles one-way

Emissions Factors for Auto Travel (From Table 3):

	Auto Trip End Factor	Auto VMT Factor
ROG Factor	4.98 grams per trip	0.55 grams per mile
NOx Factor	2.05	1.02
PM10 Factor	0	0.45

Emissions Factors for Van Travel (From Table 2, baseline vehicles, 8501-10,000 lbs.):

	Van VMT Factor
ROG Factor	0.58 grams per mile
NOx Factor	1.60
PM10 Factor	0.56

Calculations:

Annual Auto Trips Reduced = [(D)*(R)*(A)]*[1-(AA)]
=[250 * 2,134 * 0.83]*[1-0.75]
= 110,701 annual auto trips reduced

Annual Auto VMT Reduced = [(D) *(R)*(A)] * [(L) - (AA) * (LL)]
=[250 * 2,134 * 0.83] * [48-0.75*5]
=[442,805] * [48-3.75]
= 19,594,121 annual auto VMT reduced

Annual Emission Reductions = (lbs. per year)

[(Annual Auto Trips Reduced) * (Auto Trip End Factor)
+ (Annual Auto VMT Reduced) * (Auto VMT Factor) - (Van VMT)*(Van VMT factor)]/454

ROG: [(110,701) * (4.98) + (19,594,121) * (0.55) - (2,328,000) * (0.58)]/454 = **21,978 lbs. per year**
NOx: [(110,701) * (2.05) + (19,594,121) * (1.02) - (2,328,000) * (1.60)]/454 = **36,317 per year**
PM10: [(110,701) * (0) + (19,594,121) * (0.45) - (2,328,000) * (0.56)]/454 = **16,550 lbs. per year**

Capital Recovery Factor (CRF) = $\frac{(1 + i)^n(i)}{(1 + i)^n - 1} = \frac{.0525}{0.05} = 1.05$ *where n = project life (1 year)*
(From Table 8) *and i= discount rate (5%)*

Cost-Effectiveness of Funding Dollars = (CRF * Funding) / (ROG + NOx + PM10)
=(1.05 *170,352) / (21,978 + 36,317 + 16,550) = **$2 per lb.**

FOR CMAQ PROJECTS ONLY:

Once emissions reductions have been calculated, add them together (21,978 + 36,317 + 16,550 = 74,845) and convert emissions reductions to kg/day:

$$\frac{\text{lbs. reduced per year}}{\text{2.2 lbs./kg * 365 days/year}} = \frac{74,845}{2.2 * 365} = \mathbf{93\ kg/day}$$

Signal Coordination

Project definition: Improvements to signal timing that reduce overall vehicle stops and delays and that give transit vehicles priority. These include traffic signal synchronization, interconnection, improved timing projects, and transit signal priority projects. (Signal timing and other actions that increase traffic speeds and flows to the detriment of overall traffic performance or that offer a significant inducement to travel by auto are not air quality beneficial. Speed improvements to higher than 30 mph increase NOx emissions and may discourage walking and bicycling. These results may be counterproductive to meeting clean air goals.)

How emissions are reduced: Emission reductions in reactive organic gases (ROG) and nitrogen oxides (NOx) are associated with increasing average traffic speeds to up to 30 mph. (NOx emissions start increasing when average speeds are over 30 mph.)

Travel growth degrades project performance over time. Traffic flow improvements that occur immediately after implementation of the project decline to no improvement by the end of the effectiveness period. As a result, the methodology averages speed improvements over the effectiveness period by taking one-half of the first day benefits.

Need to know:
Funding dollars
Number of operating days per year
Traffic volumes for the congested periods of the day
Length of the roadway segment impacted by the project
Before and after average traffic speeds

The following information may need to be entered separately for each road segment and congested period (i.e. AM peak and PM peak) affected by the project. Vehicle speeds should correspond to the specified traffic volume.

Inputs	**Default**	**Units**	**Comments**
Funding Dollars (**Funding**)		dollars	
Effectiveness Period (**Life**)	5	years	
Days (**D**)	250	operating days per year	Default equals weekdays.
Length (**L**) of congested roadway segment		miles	Length of roadway that is impacted by the project.
Traffic Volume during congested period (**Congested Traffic**)		trips per day	Traffic volumes during congested period.

Emission Factor Inputs

	Example (10 mph)	Units	Example (13 mph)	Units
	Before Speed Factor		**After Speed Factor**	
ROG Factor	1.58	grams/mile	1.20	grams/mile
NOx Factor	1.78	"	1.60	"
PM10 Factor	0	"	0	"

Emission Factors are dependent on the **before-project** and **after-project** average traffic speeds. To select emission factors for various speeds, refer to Table 4 at the end of the document. The factors above are for before-project speed 10 mph and after-project speed 13 mph.

In the example, the before-project speed is 10 mph and the maximum average speed increase over the project effectiveness period is 25% from the speed increase table below. Therefore, the resulting after-project speed used in the table above to find the after-speed emission factors is 12.5 mph. In the example, 12.5 mph is rounded to 13 mph to find the corresponding emission factor. The emission factors in Table 4 can also be interpolated.

If speeds are unknown, average traffic speed can be estimated using the segment length (L) and a travel time (T) for vehicles passing through the segment. (Speed = L/T). After-project speeds can also be estimated by using the following information:

Before Condition	After Condition	Percent Increase in Speed
Non-interconnected, pre-timed signals with old timing plan	Advanced computer-based control	**25%**
Interconnected, pre-timed signals with old timing plan	Advanced computer-based control	**17.5%**
Non-interconnected signals with traffic-actuated controllers	Advanced computer-based control	**16%**
Interconnected, pre-timed signals with actively managed timing	Advanced computer-based control	**8%**
Interconnected, pre-timed signals with various forms of master control and various qualities of timing plans	Optimization of signal timing plans. No changes in hardware	**12%**
Non-interconnected, pre-timed signals with old timing plan	Optimization of signal timing plans	**7.5%**

Sources: Federal Highway Administration, "Urban and Suburban Highway Congestion, Working Paper No. 10," Washington, D.C., December 1987; Caltrans, *Fuel Efficient Traffic Signal Management (FETSIM) Grant Program for Local Governments 1992 Grant Applications Manual*, 1991.

Formulas **Units**

Annual Project VMT (**VMT**) = (D) * (L) * (Congested Traffic) miles/year

Annual Emission Reductions (ROG, NOx, and PM10) = lbs/year

0.5 * [(VMT)*(Before Speed Factor - After Speed Factor)]/454

Note: Initial speed improvements decline to zero improvement by the end of the effectiveness period. In order to account for this, the emission reduction equation reduces initial emission reduction benefits by one half.

$$\text{Capital Recovery Factor (CRF)} = \frac{(1 + i)^n (i)}{(1 + i)^n - 1}$$

where: i = discount rate (Assume 5 percent)
n = project life

Cost-Effectiveness of
Funding Dollars = (CRF * Funding) / (ROG + NOx + PM10) dollars/lb

Note: The Federal Highway Administration requests that emission reductions from CMAQ projects be reported as kilograms/day. The conversion is

(lbs per year) / [(2.2) (365)] = kilograms/day*

Traffic Signal Coordination

The City's master traffic signal controller was replaced with a new controller with expanded capacity. This allowed 26 more intersections to be coordinated.

Inputs to Calculate Cost-Effectiveness:

Funding Dollars (Funding): $90,000
Effectiveness Period (Life): 5 years
Days of use/year (D): 250
Length of congested roadway segment (L): 8.07 miles
Traffic Volume during congested period (Congested Traffic): 88,643 trips per day
Before Speed: 28 mph
After Speed: 33 mph

Emissions Factor Inputs (From Table 4):

	Before Speed Factor	After Speed Factor
ROG Factor	0.51 grams per mile	0.43 grams per mile
NOx Factor	1.14	1.13
PM10 Factor	0	0

Calculations:

Annual Project VMT (VMT) = (D) * (L) * (Congested Traffic)
=250 * 8.07 * 88,643 = 178,837,253 annual miles

Annual Emission Reductions (ROG, NOx, and PM10) in lbs. per year

= [(.50)*(VMT)*(Before Speed Factor - After Speed Factor)]/454 grams per lb.

ROG: [(.50)*(178,837,253) *(0.51 - 0.43)]/454 = **15,757 lbs. per year**

NOx: [(.50)*(178,837,253) *(1.14 - 1.13)]/454 = **1,970 lbs. per year**

PM10: [(.50)*(178,837,253) *(0-0)]/454 = **0 lbs. per year**

Capital Recovery Factor (CRF) = $\frac{(1+i)^n(i)}{(1+i)^n - 1}$ = .23 *where n = project life (5 years) and i = discount rate (5%)*
(From Table 8)

Cost-Effectiveness
of Funding Dollars = (CRF * Funding)/(ROG + NOx + PM10) = [.23 * 90,000] / 17,727
= $1 per lb.

FOR CMAQ PROJECTS ONLY:

Once emissions reductions have been calculated, add them together (15,727 + 1,970 = 17,727) and convert emissions reductions to kg/day: $\frac{\text{lbs. reduced per year}}{\text{2.2 lbs./kg * 365 days/year}} = \frac{17{,}727}{2.2 * 365}$ = **22 kg/day**

Bicycle Facilities

Project definition: Bicycle paths (Class 1) or bicycle lanes (Class 2) are targeted to reduce commute and other non-recreational auto travel. Class 1 facilities are paths that are physically separated from motor vehicle traffic. Class 2 facilities are striped bicycle lanes giving preferential or exclusive use to bicycles. Bike lanes should meet Caltrans' full-width standard depending on street facility type.

How emissions are reduced: Emission reductions result from the decrease in emissions associated with auto trips replaced by bicycle trips for commute or other non-recreational purposes.

Need to know:

Funding dollars
Number of operating days per year
Average length of bicycle trips
Average daily traffic volume on roadway parallel to bicycle project
City population
Project class (1 or 2)
Types of activity centers in the vicinity of the bicycle project
Length of bicycle path or lane

Inputs	Default	Units	Comments
Funding Dollars (**Funding**)		Dollars	
Effectiveness Period (**Life**)	15	Years	Class 1 projects - 20 years Class 2 projects - 15 years
Days (**D**)	200	Days of use/year	Consider local climate in number of days used.
Average Length (**L**) of bicycle trips	1.8	Miles per trip in one direction	Default is based on the National Personal Transportation Survey
Annual Average Daily Traffic (**ADT**)		Trips per day	Two-direction traffic volumes on roadway parallel to bike project. MAXIMUM IS 30,000.
Adjustment (**A**) on ADT for auto trips replaced by bike trips from the bike facility.	.0020		See Adjustment Factors table on the next page. Adjustments are based on facility class, ADT, project length, and community characteristics.
Credit (**C**) for Activity Centers near the project.	.0005		See Activity Centers table on the next page.

ADJUSTMENT FACTORS				
BIKE FACILITY CLASS	**AVERAGE DAILY TRAFFIC (ADT)**	**LENGTH OF BIKE PROJECT** (one direction)	**ADJUSTMENT FACTORS FOR CITIES WITH POP. ≥ 250,000** and non-university towns < 250,000	**ADJUSTMENT FACTORS FOR UNIVERSITY TOWNS WITH POP. < 250,000**
Class 1 (bike path) & Class 2 (bike lane)	ADT ≤ 12,000 vehicles per day	≤ 1 mile	.0019	.0104
		>1 & ≤ 2 miles	.0029	.0155
		> 2 miles	.0038	.0207
Class 1 (bike path) & Class 2 (bike lane)	12,000< ADT ≤24,000 vehicles per day	≤ 1 mile	.0014	.0073
		>1 & ≤ 2 miles	.0020	.0109
		> 2 miles	.0027	.0145
Class 2 bike lane	24,000< ADT ≤30,000 vehicles per day Maximum is 30,000	≤ 1 mile	.0010	.0052
		>1 & ≤ 2 miles	.0014	.0078
		> 2 miles	.0019	.0104

When evaluating the impact of a new bike project, it is important to consider the location of the bike facility. What types of destinations are accessible from the project? How many of these activity centers are within one-half mile of the facility? How many are within a quarter of a mile? Examine the activity centers in the vicinity of the project and compare them to the list below. Select the credit factor that corresponds to the number of activity centers in the surrounding area.

ACTIVITY CENTERS CREDITS		
Types of Activity Centers: *Bank, church, hospital or HMO, light rail station (park & ride), office park, post office, public library, shopping area or grocery store, university or junior college.*		
Count your activity centers. If there are…	**Credit (C) Within 1/2 mile**	**Credit (C) Within 1/4 mile**
At least 3	.0005	.001
More than 3 but less than 7	.001	.002
7 or more	.0015	.003

Emission Factor Inputs for Auto Travel

	Default	**Units**	**Default**	**Units**
	Auto Trip End Factor		**Auto VMT Factor**	
ROG Factor	3.26	grams/trip	.36	grams/mile
NOx Factor	1.56	"	.71	"
PM10 Factor	0	"	.45	"

These default emission factors are for an 11-15 year effectiveness period. See Table 3 to select emission factors for different effectiveness periods.

Formulas	**Units**
Annual Auto Trip Reduced = (D) * (ADT) * (A + C)	trips/year
Annual Auto VMT Reduced = (Auto Trips) * (L)	miles/year
Annual Emission Reductions (ROG, NOx, and PM10) =	lbs./year

[(Annual Auto Trips Reduced)*(Auto Trip End Factor)
+ (Annual Auto VMT Reduced)*(Auto VMT Factor)]/454

Capital Recovery Factor (CRF) = $\dfrac{(1 + i)^n (i)}{(1 + i)^n - 1}$

where: i = discount rate (Assume 5 percent)
n = project life

Cost-Effectiveness of
Funding Dollars = (CRF * Funding) / (ROG + NOx + PM10) dollars/lb.

Note: The Federal Highway Administration requests that emission reductions from CMAQ projects be reported as kilograms/day. The conversion is

(lbs. per year) / [(2.2) (365)] = kilograms/day*

Documentation: Adjustment factors were derived from a limited set of bicycle commute mode split data for cities and university towns in the southern and western United States (Source: FHWA National Bicycling And Walking Study, 1992). This data was then averaged and multiplied by 0.7 to estimate potential auto travel diverted to bikes. On average, 70% of all person trips are taken by auto (Source: 1991 Statewide Travel Survey), and it is these trips that can be considered as possible auto trips reduced. Finally, this number was multiplied by 0.65 to estimate the growth in bicycle trips from construction of the bike facility. Sixty-five percent represents the average growth in bike trips from a new bike facility as observed in before and after data for bike projects in U.S. DOT's "A Compendium of Available Bicycle and Pedestrian Trip Generation Data in the United States." Benefits are scaled to reflect differences in project structure, length, traffic intensity, community size, and proximity of activity centers. The scale has been adapted from a method developed by Dave Burch of the Bay Area Air Quality Management District (BAAQMD).

Note 1: Because ADT represents vehicles passing a single point, it may neglect vehicles that travel only a short distance on the corridor and, as a result, underestimate total vehicle trips. Therefore, the number of vehicles diverted to bicycles may be underestimated in this method. If actual vehicle trips in the corridor are known, this number should be used in place of ADT.

Note 2: Bicycle usage data is limited. From the data currently available, a positive correlation has been observed between the percentage of an area's arterials that have full width bike lanes, and the percentage of commuters who bike to work. Simply put, more bike lanes are associated with more bike commuting. More specifically, for an area with a given ratio of bike lanes to arterials, we observe that roughly one-fourth of that ratio is equal to the percentage of commuters that bike to work. More research and data are needed to confirm this relationship and to clarify the causes of this positive correlation.

Class 2 Bikeway Facility

The new Class 2 bike lanes are a critical link in the city bike system, allowing residents bicycle access to education, employment, shopping, and transit. Within one-half mile of the project, there is a college, a shopping center, a light rail station, and an office building. The project includes installation of new pavement, signage, and Class 2 bike lane striping along both sides of 1.13 miles of arterials. This is primarily a college town, with a population of 128,000.

Inputs to Calculate Cost-Effectiveness:

Funding Dollars **(Funding)**: $55,000
Effectiveness Period **(Life)**: 15 years
Days **(D)**: 200
Average Length **(L)** of bicycle trips: 1.8 miles
Annual Average Daily Traffic **(ADT)**: 16,000
Adjustment **(A)** on ADT for auto trips replaced by bike trips from the bike facility: 0.0109
Credit **(C)** for Activity Centers near the project: 0.001

Emissions Factors (From Table 3, for a 15-year Life):

	Auto Trip End Factor	Auto VMT Factor
ROG Factor	3.26 grams/trip	0.36 grams/ mile
NOx Factor	1.56	0.71
PM10 Factor	0	0.45

Calculations:

Annual Auto Trip Reduced = (D) * (ADT) * (A + C)
= (200) * (16,000) * (0.0109 + 0.001)
= 38,080

Annual Auto VMT Reduced = (Auto Trips) * (L)
= (38,080) * (1.8)
= 68,544

Annual Emission Reductions (ROG, NOx and PM10) in lbs. per year

= [(Annual Auto Trips Reduced) * (Auto Trips End Factor)
+ (Annual Auto VMT Reduced) * (Auto VMT Factor)] /454

ROG: [(38,080 * 3.26 + 68,544 * 0.36)]/454 = **328 lbs. per year**

NOx: [(38,080 * 1.56 + 68,544 * 0.71)]/454 = **238 lbs. per year**

PM10: [(38,080 * 0 + 68,544 * 0.45)]/454 = **68 lbs. per year**

Capital Recovery Factor (CRF): $\frac{(1 + i)^n(i)}{(1 + i)^n - 1}$ *Where n = project life (15 years) and i = discount rate (5%)*

(From Table 8)

$$= \frac{0.104}{1.08} = \mathbf{.10}$$

Cost-Effectiveness of Funding Dollars: (CRF * Funding) / (ROG + NOx + PM10)

=[.10 *55,000] / [328 + 238 + 68]

= $8 per lb.

FOR CMAQ PROJECTS ONLY:

Once emissions reductions have been calculated, add them together (328 + 238 + 68= 634) and convert lbs. of emissions reductions per year to kg/day:

$$\frac{\text{lbs. reduced per year}}{2.2 \text{ lbs./kg} * 365 \text{ days/year}} = \frac{634}{2.2 * 365} = \mathbf{1\ kg/day}$$

Telecommunications

Project definition: Programs and equipment that enable teleconferencing, or telecommuting, from home or from a neighborhood center.

How emissions are reduced: Emissions are reduced when auto trips are replaced with (1) home-based telecommuting, (2) teleconferencing, or (3) shorter auto trips to a neighborhood telecommuting center.

Need to know:
Funding dollars
Work weeks per year
Weekly one-way auto trips eliminated (i.e., home-work trips or work-meeting trips)
Average length of auto trips eliminated
(i.e., distance from home to work or from work to meeting)
Weekly one-way auto trips to telesite
Average length of auto trips to telesite

Inputs	**Default**	**Units**	**Comments**
Funding Dollars (**Funding**)		dollars	
Effectiveness Period (**Life**)	5	years	If no equipment was purchased, enter the number of years funding is available.
Inputs for Trips Eliminated			
Auto Trips (**T**) eliminated		trips one-way/week	Examples: (1) For home-based telecommute projects--the number of auto trips eliminated to and from the workplace per week. (2) For teleconferencing projects--the number of auto trips eliminated to and from the meeting site during an average week. (3) For telecommute center--the number of auto trips that had been made to the worksite before using the telecenter.

Inputs	Default	Units	Comments
Length (**L**) of Auto Trips eliminated	16	miles one direction/trip	Examples: (1) For telecommuting--average distance from home to work (default is 16 miles), (2) For teleconferencing--average distance from work to meeting site. (3) For telecenter--average distance from home to worksite before using telecenter
Weeks (**W**)		weeks (of operation)/year	Examples: (1) Home-based telecommute --50 weeks, (2) Teleconferencing--52 weeks. (3) Telecenter--50 weeks.
Inputs for Trips Added			
New Auto Trips (**New T**)		trips one-way/week	Examples: (1) For home-based telecommuting, enter 0. (2) For teleconference, enter number of auto trips to and from the teleconference site. (3) For telecenter, enter the number of auto trips to and from the telecenter for a week.
New Auto Trip Length (**New L**)		miles one direction/trip	Examples: (1) For home-based telecommuting, enter 0. (2) For teleconference--average distance from home to center. (3) For telecenter--average distance from work to teleconference center.

Emission Factor Inputs for Auto Travel

	Default	Units	Default	Units
	Auto Trip End Factor		**Auto VMT Factor**	
ROG Factor	4.98	grams/trip	0.55	grams/mile
NOx Factor	2.05	"	1.02	"
PM10 Factor	0	"	0.45	"

To locate emission factors, refer to emission factor tables at the end of the document. Defaults are for average light-duty cars and trucks plus motorcycles for 1 to 5 years effectiveness period. See Table 3 to select emission factors for different effectiveness periods.

Formulas **Units**

Annual Auto Trips Reduced = W * [(T) - (New T)]
trips/year

Annual Auto VMT Reduced = W * [(T)*(L) - (New T)*(New L)] miles/year

Annual Emission Reductions (ROG, NOx, and PM10) = lbs/year
[(Annual Auto Trips Reduced)*(Auto Trip End Factor)
+ (Annual Auto VMT Reduced)*(Auto VMT Factor)]/454

Capital Recovery Factor (CRF) = $\frac{(1 + i)^n (i)}{(1 + i)^n - 1}$

where: i = discount rate (Assume 5 percent)
n = project life

Cost-Effectiveness of
Funding Dollars = (CRF * Funding) / (ROG + NOx + PM10) dollars/lb

Note: The Federal Highway Administration requests that emission reductions from CMAQ projects be reported as kilograms/day. The conversion is

(lbs per year) / [(2.2) (365)] = kilograms/day*

(Note: If the project includes both home-based telecommuting as well as teleconferencing or telecenters, then the formula should be run separately for each aspect of the project.)

County Probation Videophone Project

A videophone-interviewing project is implemented by the County Probation Department.
Videophone equipment is installed for $65,000 at the branch probation offices and two detention centers.
Videophone interviewing of 5,000 inmates per year saves 200 one-way trips per week to and from detention centers (a distance of 29 miles on average).

Inputs to calculate cost-effectiveness:

Funding Dollars (Funding): $65,000
Effectiveness Period (Life): 5 years
One-Way Auto Trips Eliminated Per Week (T): 200
Length (L) of Auto Trips Eliminated: 29 miles one-way
Weeks (W) = 50 weeks
New Auto Trips (New T): 0
New Auto Trip Length (New L): not applicable

Emissions Factors for Auto Travel (From Table 3):

	Auto Trip End Factor	Auto VMT Factor
ROG Factor	4.98 grams per trip	0.55 grams per mile
NOx Factor	2.05	1.02
PM10 Factor	0	0.45

Calculations:

Annual Auto Trips Reduced = (W)*[(T) - (New T)]
=50 * (200-0) = 10,000
Annual Auto VMT Reduced = (W)*[(T)*(L) - (New T)*(New L)]
= (50)*[(200)*(29) - 0] = 290,000

Annual Emission Reductions (ROG, NOx, and PM10)
= [(Annual Auto Trips Reduced) * (Auto Trip End Factor)
+ (Annual Auto VMT Reduced) * (Auto VMT Factor)]/454

ROG: [(10,000) * (4.98) + (290,000) * (0.55)]/454 = **461 lbs. per year**
NOx: [(10,000) * (2.05) + (290,000) * (1.02)]/454 = **697 lbs. per year**
PM10: [(10,000) * (0) + (290,000) * (0.45)]/454 = **287 lbs. per year**

Capital Recovery Factor(CRF)= **(From Table 8)** $\frac{(1+i)^n(i)}{(1+i)^n - 1} = \frac{.0638}{0.276} = 0.23$ *where n= project life (5 years) and i = discount rate (5%)*

Cost-Effectiveness of Funding Dollars = (CRF * Funding) / (ROG + NOx + PM10)
=(0.23*65,000) / (461 + 697 + 287) = **$ 10 per lb.**

FOR CMAQ PROJECTS ONLY:

Once emissions reductions have been calculated, add them together (461 + 697 + 287 = 1445) and convert emissions reductions to kg/day:

$$\frac{\text{lbs. reduced per year}}{2.2 \text{ lbs./kg} * 365 \text{ days/year}} = \frac{1445}{2.2 * 365} = \mathbf{2\ kg/day}$$

Ridesharing and Pedestrian Facilities

Project definition: Ridesharing programs replace drive-alone auto trips by encouraging carpooling and other less polluting modes of travel. Pedestrian facilities replace auto trips by providing or improving pedestrian access. An example is a pedestrian passageway over several lanes of heavy traffic providing safe walking access to adjacent activity centers.

How emissions are reduced: Ridesharing reduces emissions when drive-alone auto trips are replaced with less polluting modes of travel. Pedestrian facilities reduce emissions when auto trips are replaced by walking.

Need to know:
Funding dollars
Work weeks or operating weeks per year
Weekly one-way auto trips eliminated
Average length of auto trips eliminated

Inputs	Default	Units	Text Comments
Funding Dollars (**Funding**)		dollars	
Effectiveness Period (**Life**)	1	year	Ridesharing: Enter 1 year. Pedestrian: Enter 20 years.
Inputs for Trips Eliminated			
Auto Trips (**T**) eliminated		trips one-way/week	The number of auto trips eliminated per week to and from workplace (for ridesharing) or to and from activity center (for pedestrian projects).
Length (**L**) of Auto Trips eliminated	16	miles one direction/trip	Default (16 mi.) is for ridesharing projects and equals the average distance from home to work. Pedestrian projects should use the average distance of auto trip to adjacent activity center. One mile is suggested. This is the average distance of pedestrian trips.
Weeks (**W**)	52	weeks (of operation)/year	If trips eliminated (T) is based on employee numbers that exclude workers on sick leave, vacations, etc. then (W) equals 52. Otherwise (W) typically equals 50.

Inputs	Default	Units	Text Comments
Inputs for Trips Added			
Adjustment (**A**) for Auto Access Trips to transit, vanpools, and carpools Note: No adjustment is made on Length (L) of Auto Trips eliminated because access trip length is an insignificant portion of annual VMT reduced.	0.7		Adjustment (**A)** equals the portion of employees who do NOT drive to transit, vanpools, or carpools. Default 0.7 equals the adjustment (**A**) for areas with average transit use. Use 0.6 for high transit use (i.e., commute transit mode split >10%). Use 1.0 if Method 2 was used to determine Auto Trips (**T**) eliminated. Use 1.0 for pedestrian projects.

Emission Factor Inputs for Auto Travel

	Default	Units	Default	Units
	Auto Trip End Factor		**Auto VMT Factor**	
ROG Factor	4.98	grams/trip	0.55	grams/mile
NOx Factor	2.05	"	1.02	"
PM10 Factor	0	"	0.45	"

To locate emission factors, refer to emission factor tables at the end of the document. Defaults are for average light-duty cars and trucks plus motorcycles for 1 to 5 years effectiveness period. See Table 3 to select emission factors for different effectiveness periods.

Formulas	**Units**
Annual Auto Trips Reduced = W * T * A	trips/year
Annual Auto VMT Reduced = W * T * L	miles/year
Annual Emission Reductions (ROG, NOx, and PM10) = [(Annual Auto Trips Reduced)*(Auto Trip End Factor) + (Annual Auto VMT Reduced)*(Auto VMT Factor)]/454	lbs/year

Capital Recovery Factor (CRF) = $\dfrac{(1+i)^n\,(i)}{(1+i)^n - 1}$

where: i = discount rate (Assume 5 percent)
n = project life

Cost-Effectiveness of
Funding Dollars = (CRF * Funding) / (ROG + NOx + PM10) dollars/lb

Note: The Federal Highway Administration requests that emission reductions from CMAQ projects be reported as kilograms/day. The conversion is

(lbs per year) / [(2.2) (365)] = kilograms/day*

This method can also be adapted to evaluate **Transportation Management Organizations (TMOs)** if the number of auto trips eliminated by the program is known.

Ridesharing ***(Optional Method 1)***

For ***ridesharing programs*** where the average number of daily peak-period employees and Average Vehicle Ridership (AVR) are known, you can use the following formula to find Auto Trips Eliminated (**T**). Auto Trips Eliminated (**T**) is needed in the above formulas to calculate **Annual Auto Trips Reduced** and **Annual Auto VMT Reduced**.

$$\mathbf{T} \text{ trips/week} =$$

$$2 \text{ trips/day} * 5 \text{ days/week} * \text{Peak-Period Employees} * \left[\frac{1}{\text{Baseline AVR}} - \frac{1}{\text{New AVR}} \right]$$

Notes: (1) The **New AVR** is the AVR for the current year. The **Baseline AVR** occurred before the ridesharing program was implemented. (2) The number of days/week should be adjusted to the appropriate operating schedule for the company or agency. (3) Sometimes the number of employees in the work force changes over time. In these situations, use the most current number of employees in the formula. (4) The formula is based on the assumption that AVR will revert back to the baseline without an ongoing ridesharing program. Therefore, the benefits of the program include trip reductions from previous years that are maintained, as well as additional new trip reductions. (5) If you want to evaluate a ridesharing program over several years, you should determine trips eliminated (**T**) separately for each year of the analysis period and use the average for (**T**). To do this, you need to know the AVR for each year.

Ridesharing ***(Optional Method 2)***

For ***ridesharing programs*** where a week-long commute travel survey is used, you can use the worksheets provided on the following pages to determine **Annual Auto Trips Reduced** and **Annual Auto VMT Reduced**.

- Calculate (A) number of commute employees, (B) weekly trips, and (C) weekly VMT by plugging your commute travel survey data into the "Weekly Trips and VMT Worksheet" on the next page.

- Calculate **Annual Auto Trips Reduced** and **Annual Auto VMT Reduced** by plugging the totals from the "Weekly Trips and VMT Worksheet" into the "Annual Auto Trips and VMT Reduced Worksheet."

- Enter **Annual Auto Trips Reduced** and **Annual Auto VMT Reduced** in the formulas provided in the original methodology on the previous pages to calculate emission reductions and cost-effectiveness.

Employer Rideshare Programs
Weekly Trips and VMT Worksheet

Commute mode	Employee days/week (from survey)	x	Trips/day factor	=	Trips/week subtotal	x	Access trip correction factor	=	Trips/week
Bicycle			0.0		0.0		--		0.0
Walk			0.0		0.0		--		0.0
Telecommute			0.0		0.0		--		0.0
Compressed work week day off			0.0		0.0		--		0.0
Solo drive (& motorcycle)		x	2.0	=			--	=	
Public transportation			--		--	x	1.0	=	
Carpool (default avo = 2.5)		x	0.8	=		x	1.25	=	
Vanpool (default avo = 8.5)		x	0.24	=		x	5.25	=	
	÷ 5 = (A) **Commute Employees**				x 16.0 mi. = (B) **VMT/week**				(C) **Trips/week**

* Average commute trip length.
avo = average vehicle occupancy

Employer Rideshare Programs
Annual Auto Trips and VMT Reduced Worksheet

Use Totals (A), (B), and (C) from Weekly Trip and VMT Worksheet

Annual Auto Trips Reduced

Trips/week (C)	÷	# of commute employees (A)	=	Weekly trips/ commute employee
	÷		=	

Baseline weekly trips/commute employee (Default: 8.7)	-	Weekly trips/ commute employee	=	Weekly trips/ commute employee reduced
	-		=	

Weekly trips/commute employee reduced (from row above)	x	50 weeks*	=	Annual trips/ employee reduced	x	Total # of employees**	=	**Annual Auto Trips Reduced**
	x	50	=		x		=	

Annual Auto VMT Reduced

VMT/week (B)	÷	# of commute employees (A)	=	Weekly VMT/ commute employee
	÷		=	

Baseline weekly VMT/commute employee (Default: 139)	-	Current year Wkly VMT/ employee	=	Weekly VMT/ commute employee reduced
	-		=	

Weekly VMT/commute employee reduced (from row above)	x	50 weeks*	=	Annual VMT/ employee reduced	x	Total # of employees**	=	**Annual Auto VMT Reduced**
	x	50	=		x		=	

* A 50-week default is used since the number of commute employees excludes workers on sick leave and vacation. If the worksite is not in operation year-round, adjust the number accordingly.

** If the weekly travel survey includes part-time employees, count them proportionately to their commute days, e.g., an employee working two days a week counts as 0.40 employee (2/5 = 0.40).

Baseline weekly VMT and trips per commute employee is generally calculated from survey data the year before the program started. If baseline figures are not available, use the defaults provided.

Use the Annual Auto Trips Reduced and the Annual Auto VMT Reduced totals from this worksheet in the formula for calculating emission reductions from ridesharing programs.

Worksheet Calculations

Auto trips and VMT reduced equal the difference between the trips and VMT per employee before and after the program has been implemented, multiplied by the number of employees at the worksite(s).

Calculating Annual Auto Trips Reduced

Using "Weekly Trips and VMT Worksheet," add “employee days/week” for each commute mode and divide the sum by 5 (days) to get “# of commute employees.”

Multiply "employee days/week" for each commute mode by the "trips/day factor," and multiply that total by the "access trip correction factor" to get "trips/week" for each commute mode.

Using "Annual Auto Trips and VMT Reduced Worksheet," add the "trips/week" for each commute mode to get total "trips/week." Divide "trips/week" by the "# of commute employees" to get "weekly trips/commute employee."

Subtract “weekly trips/commute employee” from the “baseline weekly trips/commute employee” to obtain “weekly trips/commute employee reduced.”

Multiply “weekly trips/commute employee reduced” by 50 weeks to get “annual trips/commute employee reduced.”

Multiply “annual trips/commute employee reduced” by the “total # of employees” at the worksite(s) to obtain “annual auto trips reduced.”

Calculating Annual Auto VMT Reduced

Multiply "employee days/wk" for each commute mode by the "trips/day factor" to get "trips/week subtotal" for each commute mode.

Add "trips/week subtotal" for each commute mode and multiply the sum by the "average commute distance" to get "VMT/week." Divide "VMT/week" by the "# of commute employees" to get "weekly VMT/commute employee."

Subtract “weekly VMT/commute employee” from the “baseline weekly VMT/commute employee” to obtain “weekly VMT/commute employee reduced.”

Multiply “weekly VMT/commute employee reduced” by 50 weeks to get “annual VMT/commute employee reduced.”

Multiply “annual VMT/commute employee reduced” by the “total # of employees” at the worksite(s) to obtain “annual auto VMT reduced.”

Worksheet Assumptions

Average one-way commute trip length: The 1995 National Personal Transportation Survey indicated the average home-to-work trip is 11-12 miles. The Southern California State of the Commute Survey estimated the average home-to-work trip to be 16-17 miles. However, since surveys of employer Transportation Demand Management (TDM) programs (100+ employees) have shown a commute distance closer to 16-17 miles, a 16-mile average is used for this methodology.

Trips/day factor: It is assumed that bicycle, telecommute, compressed work week day off, and walk commute modes do not generate any commute-related vehicle trips. Solo driving and motorcycles generate 2 commute trips per day. Carpools and vanpools generate varying trips/day based on the number of passengers. For example, a person in a carpool that averages 2.5 occupants generates 0.8 trips per day (1 vehicle divided by 2.5 occupants equals 0.4 trips, multiplied by 2 trips equals 0.8 trips per day).

Default carpool and vanpool factors: Based on average vehicle occupancy of 2.5 for a carpool and 8.5 for a vanpool. (Source: 1996 Southern California State of the Commute Survey)

Access trip correction factor: It is assumed that 50% of public transportation commuters, 50% of vanpoolers, and 10% of carpoolers drive a personal vehicle to the mode access point. (Source: Percentages developed by California Air Resources Board, using 1996 Southern California State of the Commute Survey, Bay Area Air Quality Management District data, and emission reduction analyses of California motor vehicle fee TDM projects.) Example: A vanpool averaging 8.5 occupants generates 5.25 one-way vehicle trips because 1 van is driven and 4.25 passengers (50%) drive to the vanpool access point. Over five times more one-way trips are generated (5.25 instead of 2) than if there were no access trips, so 5.25 is the access trip correction factor. Access trips are included in trips/week calculations but not VMT/week calculations because they add a significant amount of trips to overall commute travel but a fairly insignificant amount of VMT.

Default baseline weekly trips and VMT per employee: 8.7 trips/week, 139 VMT/week. The 1995 National Personal Transportation Survey indicates the average daily commute vehicle trip rate is 1.75. 1.75 multiplied by 5 days per week equals 8.7 trips per week. 8.7 trips per week multiplied by a 16-mile average commute distance equals 139 VMT per week. (Note: Weekly trip and VMT rates per employee are calculated in order to compensate for not having completed surveys from every employee and/or for having a different number of employees in the baseline and current years.)

County Trip Reduction Program

A county conducts a comprehensive employee trip reduction program, which includes vanpool and carpool programs, telecommuting, compressed work schedules, and guaranteed emergency transportation.

Inputs to Calculate Cost-Effectiveness:

Funding Dollars (Funding): $140,505

Effectiveness Period (Life): 1 year

One-Way Auto Trips Eliminated Per Week (T) Using Optional Method 1:

T = 2 trips/day * 5 days/week * peak period employees * [1/Baseline AVR - 1/New AVR]

where baseline AVR is 1.13, new AVR is 1.19, and there are 15,750 peak period employees.

Therefore, T = 2 trips/day * 5 days/week * 15,750 peak period employees * [1/1.13 - 1/1.19] = 6300 trips

Length (L) of Auto Trips Eliminated: 16 miles

Weeks (W) = 52 weeks

Adjustment (A): 0.7 For auto access trips to transit, vanpools, and carpools

Emissions Factors for Auto Travel (From Table 3):

	Auto Trip End Factor	Auto VMT Factor
ROG Factor	4.98 grams per trip	0.55 grams per mile
NOx Factor	2.05	1.02
PM10 Factor	0	0.45

Calculations:

Annual Auto Trips Reduced = (W)*(T)*(A)
= 52 * 6300 * .7 = 229,320

Annual Auto VMT Reduced = (W) * (T) * (L)
=52 * 6300 * 16 miles
= 5,241,600 annual VMT reduced

Annual Emission Reductions (ROG, NOx, and PM10)

= [(Annual Auto Trips Reduced) * (Auto Trip End Factor)
+ (Annual Auto VMT Reduced) * (Auto VMT Factor)]/454

ROG: [(229,320) * (4.98) + (5,241,600) * (0.55)]/454 = **8,865 lbs. per year**

NOx: [(229,320) * (2.05) + (5,241,600) * (1.02)]/454 = **12,812 lbs. per year**

PM10: [(229,320) * (0) + (5,241,600) * (0.45)]/454 = **5,195 lbs. per year**

Capital Recovery Factor (CRF) = $\frac{(1+i)^n(i)}{(1+i)^n - 1} = \frac{.0525}{0.05} = 1.05$ *where n = project life (1 year)*
(From Table 8) *and i = discount rate (5 %)*

Cost-Effectiveness of Funding Dollars = (CRF * Funding) / (ROG + NOx + PM10)
=(1.05 * 140,505) / (8,865 + 12,812 + 5,195) = **$5 per lb.**

FOR CMAQ PROJECTS ONLY:

Once emissions reductions have been calculated, add them together (8,865 + 12,812 + 5,195) = 26,872) and convert emissions reductions to kg/day:

$$\frac{\text{lbs. reduced per year}}{2.2 \text{ lbs./kg} * 365 \text{ days/year}} = \frac{26,872}{2.2 * 365} = \mathbf{33\ kg/day}$$

Table 1 Bus Emission Factors *(VMT Factors in grams/mile)*

Older Urban Transit Buses (1973-1995)

Pollutant	Year	Diesel Fuel	Compressed Natural Gas (CNG) Liquified Natural Gas (LNG)
Organic Gases	1973-83	4.2	Not Applicable
(Use as ROG)	1984+	3.7	3.7
Nitrogen	Pre-1984	30.4	Not Applicable
Oxides (NOx)	1984-90	22.5	Not Applicable
	1991-95	21.5	12.3
Particulate	Pre-1984	2.28	Not Applicable
Matter	1984-90	1.45	Not Applicable
(PM10)	1991-93	.70	.62
	1994-95	.64	.59

1996 Urban Transit Bus Emission Factors and Commuter Express Bus Emission Factors

	Urban Transit Bus – 15 mph			**Commuter Express Bus** – 45 mph	
	4.0 g/bhp-hr NOx Std	**2.0 g/bhp-hr NOx Std**		**4.0 g/bhp-hr NOx Std**	**2.0 g/bhp-hr NOx Std**
ROG	3.1 g/mi	3.1 g/mi		1.1 g/mi	1.1 g/mi
NOx	17.2 g/mi	8.6 g/mi		12.5 g/mi	6.3 g/mi
PM10	0.6 g/mi	0.6 g/mi		0.5 g/mi	0.5 g/mi

Source: MVEI7G, Certification and In-Use Tests. CNG/LNG emission factors are based on limited extended in-use testing and are subject to a larger error band than diesel emission factors. ROG and NOx are exhaust emissions.

PM10 factors include exhaust, tire wear (.065 g/mi.), brake wear (.013 g/mi.), and paved road dust (.422 g/mi.). The road dust portion of the PM10 factor is based on U.S. EPA's Compilation of Air Pollutant Emission Factors (AP-42, January 1995). Silt loading and vehicle weight data used as inputs to EPA's equation are from Improvement of Specific Emission Factors (BACM Project No. 1), Final Report, Midwest Research Institute, March 1996.

Note: Nitrogen Oxides (NOx) contribute to the atmospheric formation of both ozone and aerosol particulate matter. For this reason, NOx reductions are critical to reducing both pollutants.

Table 2 Medium-Duty Vehicle Emission Factors (1995 and Later)

Baseline Vehicles

Emission factors in grams per mile for chassis certified medium-duty vehicles			
Weight (lbs.)*	**ROG**	**NOx**	**PM10**
5751-8500	0.49	1.35	0.56
8501-10,000	0.58	1.60	0.56
10,001-14,000	0.75	2.45	0.56

Cleaner Vehicles

Low-emission medium-duty vehicle (LEV) emission factors in grams per mile			
Weight (lbs.)	**ROG**	**NOx**	**PM10**
5751-8500	0.24	0.77	0.56
8501-10,000	0.29	0.88	0.56
10,001-14,000	0.38	1.29	0.56

Ultra low-emission medium-duty vehicle (ULEV) emission factors in grams per mile			
Weight (lbs.)	**ROG**	**NOx**	**PM10**
5751-8500	0.15	0.77	0.50
8501-10,000	0.17	0.88	0.50
10,001-14,000	0.23	1.29	0.50

Super ultra low-emission medium-duty vehicle (SULEV) emission factors in grams per mile			
Weight (lbs.)	**ROG**	**NOx**	**PM10**
5751-8500	0.07	0.39	0.50
8501-10,000	0.09	0.44	0.50
10,001-14,000	0.12	0.62	0.50

Zero-emission medium-duty vehicle (ZEV) emission factors in grams per mile			
Weight (lbs.)	**ROG**	**NOx**	**PM10**
All weights	0	0	0.44

*Gross vehicle weights can be associated with passenger capacity as follows: 5751-8500, roughly 8 passengers; 8501-10,000, roughly 10-15 passengers; 10,001-14,000, roughly 20 passengers or more.

Source: Based on California Vehicle Exhaust Standards, current as of January 1999. Factors for ROG and NOx represent a weighted average of emission standards over a 120,000-mile life; the first 50,000 miles are assessed at the 50,000-mile standard, and the remaining 70,000 miles are assessed at the 120,000-mile standard. PM10 factors include motor vehicle exhaust (.12 g/mi. for gas/diesel, LEV; and .06 g/mi. for ULEV, SULEV), tire wear (.008 g/mi. for all), brake wear (.013 g/mi. for all), and entrained road dust (.422 g/mi. for all). The road dust portion of the PM10 factor is based on U.S. EPA's Compilation of Air Pollutant Emission Factors (AP-42, January 1995). Silt loading and vehicle weight data used as inputs to EPA's equation are from Improvement of Specific Emission Factors (BACM Project No. 1), Final Report, Midwest Research Institute, March 1996.

Table 3 Average Auto Emission Factors

Analysis Period:	1-5 Years (1997-2001)	6-10 Years (1997-2006)	11-15 Years (1997-2011)	16-20 Years (1997-2016)
ROG				
vmt (g/mi)	0.55	0.44	0.36	0.30
commute trips (g/trip)	4.98	4.03	3.26	2.70
average trips (g/trip)	2.91	2.34	1.89	1.56
NOx				
vmt	1.02	0.84	0.71	0.62
commute trips	2.05	1.78	1.56	1.39
average trips	1.49	1.33	1.20	1.11
PM10				
vmt	.45 (all years)			
trips	Not Applicable			

Source: Annual Average Emissions Inventories, EMFAC/BURDEN 7G v1.0. Includes average statewide emissions for light duty cars and trucks plus motorcycles. VMT factor equals running exhaust plus running losses divided by daily VMT. Commute trips factor equals statewide start emissions for a commute-type pre-start soak distribution plus hot soak emission divided by daily trips. The commute-type pre-start soak distribution is based on an analysis of the 1991 Statewide Travel Survey all day home-work and work-home trips. Average trips factor equals statewide start emissions plus hot soak emissions divided by daily trips.

PM10 factor includes motor vehicle exhaust (.006 g/mi.), tire wear (.008 g/mi.), brake wear (.013 g/mi.), and entrained road dust (.422 g/mi.). The road dust portion of the PM10 factor is based on U.S. EPA's Compilation of Air Pollutant Emission Factors (AP-42, January 1995). Silt loading and vehicle weight data used as inputs to EPA's equation are from Improvement of Specific Emission Factors (BACM Project No. 1), Final Report, Midwest Research Institute, March 1996.

NOTE: Light-duty vehicle emission standards require progressively cleaner fleet average emissions. This accounts for the gradual decrease in fleet average emission factors over time.

TO USE TABLE to find annual emissions related to travel: 1) select time period that corresponds to life of project, 2) multiply annual miles traveled by the VMT factor, 3) multiply annual number of trips by the trips factor, 4) add VMT emissions to trip emissions, 5) divide by 454 grams/lb to get lbs of emissions per year, 6) repeat for each pollutant. (Note: Use the commute trips factor when analyzing work trips. Use the average trips factor when analyzing a variety of trip types. The VMT factor is the same in both instances.)

Table 4 Emission Factors by Speed

Project Life 1-5 years (1997-2001)

grams/mile

mph	ROG	NOx	mph	ROG	NOx
5	**3.40**	**2.30**	**35**	**0.40**	**1.14**
6	3.04	2.20	36	0.39	1.16
7	2.67	2.09	37	0.38	1.17
8	2.31	1.99	38	0.37	1.19
9	1.94	1.88	39	0.36	1.20
10	**1.58**	**1.78**	**40**	**0.35**	**1.22**
11	1.45	1.72	41	0.34	1.25
12	1.33	1.66	42	0.33	1.28
13	1.20	1.60	43	0.33	1.31
14	1.08	1.54	44	0.32	1.34
15	**0.95**	**1.48**	**45**	**0.31**	**1.37**
16	0.90	1.44	46	0.31	1.41
17	0.85	1.40	47	0.31	1.45
18	0.79	1.36	48	0.30	1.50
19	0.74	1.32	49	0.30	1.54
20	**0.69**	**1.28**	**50**	**0.30**	**1.58**
21	0.66	1.26	51	0.31	1.64
22	0.64	1.24	52	0.31	1.69
23	0.61	1.21	53	0.32	1.75
24	0.59	1.19	54	0.32	1.80
25	**0.56**	**1.17**	**55**	**0.33**	**1.86**
26	0.54	1.16	56	0.36	1.93
27	0.52	1.15	57	0.38	2.01
28	0.51	1.14	58	0.41	2.08
29	0.49	1.13	59	0.43	2.16
30	**0.47**	**1.12**	**60**	**0.46**	**2.23**
31	0.46	1.12	61	0.57	2.32
32	0.44	1.13	62	0.67	2.42
33	0.43	1.13	63	0.78	2.51
34	0.41	1.14	64	0.88	2.61
			65	**0.99**	**2.70**

PM10 Factor is 0.45 for all speeds.

Source: EMFAC/Burden 7G v1.0, 75F, summer fuel, enhanced I/M, statewide fleet averages.

NOTE: Average ROG and NOx emissions are greatest at low and high speeds.
ROG is lowest around 50 mph and NOx is lowest around 30 mph.

Table 4A Emission Factors by Speed
For Carbon Monoxide (CO) Nonattainment Areas

Project Life 1-5 Years
Average Emission Factors for 1995-1999
grams/mile

mph	CO
5	21.89
10	12.43
15	8.58
20	6.62
25	5.44
30	4.63
35	4.05
40	3.65
45	3.45
50	3.51
55	3.97
60	5.94
65	12.39

(Source: EMFAC7F1.1/B7F, temperature 75 degrees, statewide fleet averages.)

NOTE: FHWA requests that CO emission reductions be reported for CMAQ projects. California's MV Fee Program does not request CO information. CO is a localized pollutant and not a regional pollution problem. Most projects using CMAQ and MV Fee dollars are funded primarily to reduce regional ozone and PM10 and have little impact on localized CO hot spots.

Signal coordination projects, however, may be targeted at specific CO hot spots in CO nonattainment areas. CO emission factors are included in the 1999 Edition in order to report to FHWA on these types of CMAQ projects. Reporting CO emission reductions should be limited to targeted projects located in CO nonattainment areas (Los Angeles and Imperial counties) or projects in CO maintenance areas.

In addition, CO emissions are several orders of magnitude larger than ozone precursors. CO overwhelms cost-effectiveness ratios unless CO emission reductions are scaled back significantly, typically by a factor of seven. This adjustment should be made when using cost-effectiveness ratios as a basis for funding decisions. Another option is to consider CO projects separately from ozone precursor projects.

Table 5 On-Road Nitrogen Oxides (NOx) Emission Factors for Heavy-Duty Cleaner Vehicle Projects (1998-1999)

"Before Project" Heavy-Duty DIESEL Vehicles (Baseline Emission Factors)

Vehicle Type	Gross Vehicle Weight Rating	NOx Engine Certification Emission Rates g/bhp-hr	Conversion Factors bhp-hr/mi	Emission Factors g/mi
Urban transit buses	All weights	4.0	4.3	17.2
School buses and trucks	8,501 – 14,000	4.0	1.5	6.0
School buses and trucks	14,001 – 33,000	4.0	2.3	9.2
Class 8 urban school bus	> 33,000	6.0	4.3	25.8
Class 8 trucks	> 33,000	6.0	2.6	15.6

The emission factor equals the certification rate multiplied by the conversion factor.

"After Project" Heavy-Duty Cleaner Vehicles
EXAMPLES for Compressed Natural Gas (CNG) or Liquified Natural Gas (LNG)

Vehicle Type	Gross Vehicle Weight Rating (lbs)	NOx Engine Certification Emission Rates g/bhp-hr	Conversion Factors * bhp-hr/mi	Emission Factors g/mi
Urban transit buses and Class 8 urban school buses	Transit all weights and school > 33,000	1.5 2.0 2.5	4.3 4.3 4.3	6.45 8.6 10.75
School buses and trucks	8,501 – 14,000	1.5 2.0 2.5	1.5 1.5 1.5	2.25 3.0 3.75
School buses and trucks	14,001 – 33,000	1.5 2.0 2.5	2.3 2.3 2.3	3.45 4.6 5.75
Class 8 trucks	> 33,000	1.5 2.0 2.5	2.6 2.6 2.6	3.9 5.2 6.5

*Diesel equivalent conversion factors

If the project's NOx engine certification rate is not shown in the table, multiply the appropriate rate times the conversion factor corresponding to the vehicle class to get grams per mile.

Source: ARB Criteria and Guidelines for Use of Motor Vehicle Registration Fees, June 1998 and The Carl Moyer Program Guidelines, February 1999.

Table 6 Off-Road Nitrogen Oxides (NOx) Emission Factors for Cleaner Vehicle Projects

Engine Category (HP)	Construction Equipment Defaults				
	Hours of Operation (Hrs/yr)	Load (%)	Uncontrolled Diesel NO_x **"Before Project" Baseline Engine** (g/bhp-hr)	NOx Standard 1998-2000 **"After Project" Cleaner Engine** (g/bhp-hr)	Uncontrolled Compressed Natural Gas NO_x (g/bhp-hr)
50 to 175	130	0.68	13	6.9	9
176 +	130	0.68	11	6.9	9

Operating hours can range from 130 to 1836 hours per year and load factor can vary between 0.43 and 0.78.

Engine Category (HP)	Agricultural Equipment Defaults				
	Hours of Operation (Hrs/yr)	Load (%)	Uncontrolled Diesel NO_x **"Before Project" Baseline Vehicle** (g/bhp-hr)	NOx Standard 1998-2000 **"After Project" Cleaner Vehicle** (g/bhp-hr)	Uncontrolled Compressed Natural Gas NO_x (g/bhp-hr)
50 to 175	110	0.50	13	6.9	9
176 +	110	0.50	11	6.9	9

Operating hours can range from 110 to 814 hours per year and load factor can vary between 0.48 and 0.70.

Source: ARB's Mobile Source Control Division Off-Road Model, 1997 (ARB will consider an updated off-road model in late 1999.)

Table 7 Light-Duty Vehicle Emission Factors (1995 and Later)

Baseline Vehicles

Gasoline, diesel and methanol light-duty vehicle (Tier 1) emission factors in grams per mile			
Weight (lbs.)	**ROG**	**NOx**	**PM10**
0-3750*	0.28	0.70	0.45
3751-5750**	0.36	1.10	0.45

Cleaner Vehicles

Transitional low-emission light-duty vehicle (TLEV) emission factors in grams per mile			
Weight (lbs.)	**ROG**	**NOx**	**PM10**
0-3750*	0.14	0.50	0.44
3751-5750**	0.18	0.80	0.44

Low-emission light-duty vehicle (LEV) emission factors in grams per mile			
Weight (lbs.)	**ROG**	**NOx**	**PM10**
0-3750*	0.08	0.25	0.44
3751-5750**	0.12	0.45	0.44

Ultra low-emission light-duty vehicle (ULEV) emission factors in grams per mile			
Weight (lbs.)	**ROG**	**NOx**	**PM10**
0-3750*	0.05	0.25	0.44
3751-5750**	0.06	0.45	0.44

Zero-emission light-duty vehicle (ZEV) emission factors in grams per mile			
Weight (lbs.)	**ROG**	**NOx**	**PM10**
0-3750*	0	0	0.44
3751-5750**	0	0	0.44

*All Passenger Cars; Light Duty Trucks (0-3750 lbs. Loaded Vehicle Weight)
**Light Duty Trucks (3751-5750 lbs. Loaded Vehicle Weight)

Source: Based on California Vehicle Exhaust Standards, current as of January 1999. Factors for ROG and NOx represent a weighted average of emission standards over a 100,000-mile life; the first 50,000 miles are assessed at the 50,000-mile standard, and the remaining 50,000 miles are assessed at the 100,000-mile standard. PM10 factors include motor vehicle exhaust, tire wear (.008 g/mi.), brake wear (.013 g/mi.), and entrained road dust (.422 g/mi.). The road dust portion of the PM10 factor is based on U.S. EPA's Compilation of Air Pollutant Emission Factors (AP-42, January 1995). Silt loading and vehicle weight data used as inputs to EPA's equation are from Improvement of Specific Emission Factors (BACM Project No. 1), Final Report, Midwest Research Institute, March 1996. PM10 exhaust for baseline vehicles (.006 g/mi) is based on Annual Average Inventories EMFAC/BURDEN 7G v1.0 for average statewide emissions from light-duty cars and trucks plus motorcycles. PM10 exhaust for cleaner vehicles is assumed to be negligible.

NOTE: Light-duty vehicle manufacturers are required to achieve progressively more stringent fleet average emissions over time. The emission benefits associated with fleet turnover to cleaner vehicles are already credited in the baselines of clean air plans; however, air quality funds may serve as financial incentive to private and public entities that are "early adopters" of new, cleaner vehicle technologies. Incentive programs that lead to the conversion of an agency's vehicle fleet to cleaner vehicles can be justified for a limited time. These programs should be re-evaluated periodically as to their priority for funding when compared to other emission reducing projects.

DUE TO THE INCREASING STRINGENCY OF MANUFACTURERS' FLEET AVERAGE EMISSIONS REQUIREMENTS, 1999 LIGHT-DUTY CLEANER VEHICLE PURCHASES MUST BE ULEV OR CLEANER TO BE ELLIGIBLE FOR AIR QUALITY DOLLARS.

Table 8 Capital Recovery Factors

The following table gives capital recovery factors that may be used to annualize funding dollars according to project life. The capital recovery factors calculated to two decimal places are the same for discount rates 4.75% and 5%.

Project Life	**Capital Recovery Factor for discount rates 4.75% or 5%**
1 year	1.05
3 years	0.37
5 years	0.23
7 years	0.17
10 years	0.13
12 years	0.11
15 years	0.10
20 years	0.08

The formula for the capital recovery factor is:

$$\text{Capital Recovery Factor (CRF)} = \frac{(1+i)^n\,(i)}{(1+i)^n - 1}$$

where: i = discount rate

n = project life

For example, if the project life is 1 year and the discount rate is 5%, then the capital recovery factor equals 1.05.

$$= \frac{(1+i)^n(i)}{(1+i)^n - 1} = \frac{(1+0.05)^1(0.05)}{(1+0.05)^1 - 1} = \frac{0.0525}{0.05} = 1.05$$

To determine cost-effectiveness, funding dollars are amortized over the expected project life using a discount rate. The amortization formula yields a capital recovery factor, which, when multiplied by the funding, gives the annualized funding for the project over its expected lifetime. The discount rate reflects the opportunity cost of public funds for the clean air programs. This is the level of earnings that could be reasonably expected by investing public funds in various financial instruments, such as U.S. Treasury securities. Cost-effectiveness is determined by dividing annualized funds by annual emission reductions (ROG + NOx + PM10).